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WATER ABSORPTION OF INSULATION IN PROTECTED MEMBRANE ROOFING SY--ETC(U)
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REPORT 76-38

Water absorption of insulation in protected membrane roofing systems

Cover: Insulation on protected membrane roof of Building 1053 at Ft. Wainwright in Fairbanks, Alaska. A portion of the bottom layer was removed, revealing no deterioration other than surface effects after 28 months of service.

CRREL Report 76-38

Water absorption of insulation in protected membrane roofing systems

David Schaefer

October 1976

Prepared for

DIRECTORATE OF MILITARY CONSTRUCTION
OFFICE, CHIEF OF ENGINEERS

By

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

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Current methods for evaluation of the moisture absorption of plastic insulations (ASTM-C-272-53 and ASTM-C-355-64) due to vapor pressure gradients or immersion rely on short time periods to predict long term performance. This procedure may not provide accurate information on performance since in practice insulations may absorb more moisture than these tests indicate. A series of tests were conducted on extruded polystyrene roof insulation that had been in place, exposed to environmental moisture and pressure gradients, for a maximum of 36 months. Results indicate that moisture absorption of 1.5% by volume can be expected in the field.

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PREFACE

This report was prepared by David Schaefer, Research Civil Engineer, Alaskan Projects Office, U.S. Army Cold Regions Research and Engineering Laboratory. The work was performed under DA Project 4A162121A894, *Engineering in Cold Environments*, Task 21, *Cold Regions Building Systems for Military Installations*, Work Unit 004, *Evaluation of Protected Membrane Roofs in Cold Regions.*

The principal investigator for this Work Unit was Dr. Haldor W.C. Aamot, Research Mechanical Engineer, Construction Engineering Research Branch, EED, USA CRREL. David Schaefer was associate investigator. Michael Stallion and Edwin T. Larsen, Civil Engineer Assistants, Alaskan Projects Office and Construction Engineering Research Branch respectively, performed the actual sampling of the roofs. Technical review of the report was performed by Dr. Aamot and Mr. Larsen of USA CRREL and by Mr. K. Epstein of Dow Chemical Co., Midland, Michigan.

The contents of this report are not to be used for advertising or promotional purposes. Citation of brand names does not constitute an official endorsement or approval of the use of such commercial products.

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ILLUSTRATIONS

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CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	*By*	*To obtain*
inch	25.4*	millimeter
foot	0.3048*	meter
pound/inch^2	6894.757	pascal
pound/foot^3	16.01846	kilogram/meter^3
Btu in./h ft^2 °F	0.1442279	W/m K
degrees Fahrenheit	$t_{°C} = (t_{°F} - 32)/1.8$	degrees Celsius
degrees Fahrenheit	$t_K = (t_{°F} + 459.67)/1.8$	kelvins

* Exact

WATER ABSORPTION OF INSULATION IN PROTECTED MEMBRANE ROOFING SYSTEMS

David Schaefer

INTRODUCTION

Problems associated with failure of roofing systems in cold regions have been a fact of life for designers for many years. Cullen (1965) reported that at Alaskan military installations a 71.5% failure rate exists for conventional bituminous built-up roofs. Aamot (1971) reported on the problems associated with present roof construction methods and suggested the use of protected membrane roofing systems as a possible solution to the failure problem.

Often there is little or no attempt to gather performance data on materials after installation in a structure. In this paper actual performance data on insulations in protected membrane roofing systems are presented and analyzed. The data and the analysis are concerned with the moisture absorption of the insulation. The resulting effects on its insulating value will be analyzed in a subsequent study.

Principal features of a protected membrane roof system

1. A waterproofing membrane placed on the structural deck below the insulation acts both as a vapor barrier and waterproof surface.
2. A closed cell rigid insulation is laid over the membrane to the thickness required for thermal considerations. Currently, extruded polystyrene insulation is used almost exclusively, but in general, insulation that is resistant to freeze-thaw action and is thermally acceptable with increased moisture contents found in the field should be evaluated for use in this roof system.
3. A system to prevent wind uplift and counteract buoyant forces as well as to protect the insulation is placed on top.

Reported advantages of a protected membrane roof system

1. In one type of system, the individual components are loose-laid and are free to move relative to one another, thus are unaffected by differential thermal contraction or expansion. In the alternate type of system, the components are adhered, thus reducing the need for ballast.
2. The membrane is protected in its position next to the warm structural deck and remains at a fairly stable temperature throughout the year. In addition, it combines the functions of a vapor barrier and a waterproof membrane; thus the possibility of water becoming trapped between these two elements is precluded.
3. The insulation chosen is not degraded physically by moisture and retains at least 80% of its design insulating value due to moisture absorption from long-term exposure. Water is allowed to flow past the insulation to the membrane and to the drain; thus, during cold weather, it flows to regions of higher and higher temperature.
4. The roof system is self-drying, a vital feature in cold regions and a desirable feature in most cases. Because the upper surface is not covered by an impervious membrane, any moisture that does not drain can escape to the atmosphere, driven by vapor pressure gradients.
5. The system can be placed successfully during cold weather conditions using loose-laid single-ply synthetic membranes. Aamot (1972) reported on the installation of two such roofs during January and February in Anchorage, Alaska. The large sheets of EPDM rubber were laid out at temperatures around 0°F. The lap joints were made under the protection of tent-type movable shelters and using hand-held heaters to work on the lap joint seams.

Aamot and Schaefer (1972), Baker and Hedlin (1972) and Aamot (1971) have all written about the expected advantages of the protected membrane roofing system. Each of these authors has stressed that probably the most critical component of the protected membrane roofing system is the insulation. Schaefer (1973), in a survey of currently available insulation materials, lists the following criteria for an insulation for successful incorporation into a protected membrane system:

1. Low water absorption characteristics
2. Freeze-thaw resistance
3. Low unit weight – probably less than 5 lb/ft^3
4. 10-15 psi minimum compressive strength
5. Fire retardancy
6. Compatibility with membrane
7. Low initial cost.

Many currently available insulators can meet the last five criteria, but only a few have sufficiently low water absorption and good freeze-thaw resistance. To date Dow Chemical Company Styrofoam RM has been used in the majority of protected membrane roofing installations. This is the material used on all the roofs studied in this investigation.

Since water absorption has been a major concern and widespread used of this roofing concept will be achieved only if the ability to predict long-term effects of moisture upon the performance of the selected insulation is achieved, a program to monitor the moisture characteristics of several roofs was initiated by CRREL. This report covers the investigation of eight protected membrane roofs installed during the period 1970-1973.

STUDY SITES

Currently existing protected membrane roofs in Alaska, and the roof covering the coldroom complex at CRREL in Hanover, New Hampshire, were sampled. Table I shows the location and length of service of each roof.

Table I. Location of roofs involved in sampling.

Building	*Date installed*	*Length of service (months)*
Stevens Hall*	Oct 1969	36
Building 415*	Nov 1969	35
Building 1053†	Jul 1971	28
Gruening Building*	Oct 1971	24
Consortium Library**	Jan 1972	22
K Building**	Feb 1972	21
CRREL††	Jul 1972	15
Resources Building*	Oct 1972	12

* University of Alaska, Fairbanks, Alaska
† Ft. Wainwright, Alaska
** University of Alaska, Anchorage, Alaska
†† Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.

Stevens Hall, University of Alaska, Fairbanks

A protected membrane roof was installed on this student residence hall following the development of severe problems with leaks and condensation in the built-up roofing system. It was the first such roof installed in Alaska and was a cooperative effort between the University of Alaska and Dow Chemical Company. The old built-up roof was not removed. Construction consisted of cleaning the existing built-up roof and then placing a butyl rubber membrane. Styrofoam RM insulation, and 8×16 in. concrete paver blocks. The installation was to be a temporary repair to facilitate the use of the upper floor of the dormitory building. This temporary repair has now been in place three years and apparently will not be replaced. The general appearance of the insulation is good, and no weathering due to atmospheric conditions is evident.

Building 415, University of Alaska, Fairbanks

This building is one of a group of modular apartments for married students. A protected membrane roof was installed during erection of these units because of failure in the specified elastomeric roofing material. Only one of the group received this roof and the contractor repaired the rest of the units with the specified material. These are flat roofs with roof scuppers to facilitate drainage. It is interesting to note that the roof system was placed during a relatively cold month in the Fairbanks area. The other units in this complex have a history of roof leaks and repair, but to date no repair work has been necessary on Building 415.

Building 1053, Ft. Wainwright, Alaska

This building was built in the early 1950's during an expansion of defense facilities in Alaska. Schaefer (1971) has reported on the re-roofing of this building. Basically, the entire existing built-up roof was removed, the metal decking repaired, and a protected membrane roof installed. Temperatures and heat flow measurements were made on this roof as part of a larger CRREL program to evaluate and develop roofing systems for military use. No repairs have been required on this roof to date.

Gruening Building, University of Alaska, Fairbanks

This was the first building at the University of Alaska that specified a protected membrane roofing system in the design documents. The building was to have been completed in 1971, but due to contract problems it was not occupied until spring 1973. The roof, however, was placed in 1971 and the building was unheated during the 1971-72 winter. This roof is still under warranty, hence the University has no repair data.

Consortium Library and K Building, University of Alaska, Anchorage

Both of these buildings were built during a recent expansion of the University of Alaska, Anchorage. One slight difference between these roofs and others is that the contractor used 1-in. Fesco board as a leveling course over a steel deck. Thus, the membrane, while still in a protective position, is likely to experience temperatures somewhat different from the deck temperatures. Both these roofs were placed in the middle of winter and after 22 months of service have required no repairs.

CRREL Laboratory, Hanover, New Hampshire

A protected membrane roof system was specified for the re-roofing of a portion of the laboratory building. This roof is fully instrumented and is intended as a test roof to evaluate the long-term thermal performance of this system. The structural deck is a level concrete deck; there is no slope to drain. Normally, in new construction such a feature would be undesirable. This roof was completed in August 1972.

Resources Building, University of Alaska, Fairbanks

This recently constructed building on the campus has been in service only one year. The roof is under warranty and no repair data are available.

All of the roof insulations sampled appeared to be in good shape, with no noticeable weathering due to environmental influences other than water. A majority of the roofs were placed during what are normally considered marginal weather conditions for placing any kind of roof. Only two roofs (Building 1053 and CRREL Laboratory) were placed during summer months, while both roofs at Anchorage were placed during the middle of winter. After a maximum of three years of service, reapir and maintenance have not been major items of concern.

INSULATION PROPERTIES

All insulation investigated for this project was produced by Dow Chemical Company and marketed by Amspec, a Dow subsidiary. This material is an extruded polystyrene with integral skins sold under the trademark Styrofoam. It is available in various thicknesses up to 3 in. Table II lists the physical properties of the particular Styrofoam RM that is sold exclusively for roofing.

Table II. Manufacturer's insulation specifications. From Amspec (Dow Chemical Company subsidiary) brochure on IRMA (Inverted Roof Membrane Assembly) Roofing System.

Test	*Value*
Thermal conductivity (Btu-in./hr ft^2 °F) ASTM C-177-63	0.20
Density (lb/ft^3)	2.3
Compressive strength (psi) at 0.1 in. deflection ASTM 1621-64	30.0
Water vapor transmission (perm-in.) ASTM C-355-64	0.6
Thermal expansion (in./in.) ASTM D-696-44	35×10^{-6}
Moisture absorption (% by vol) ASTM C-272-53	less than 0.1

Kaplar (1974) and Williams (1968) have both recognized that extruded polystyrene absorbs more water over extended periods of time than is shown by short-term ASTM testing methods. Kaplar ran water absorption tests for a 90-day period on Styrofoam RM. Table III shows the results of those tests.

ASTM C-272-53 describes a 24-hour immersion test of water absorption of core materials for structural sandwich construction (all types of materials, including cellular). ASTM C-240 describes a 2-hour immersion test, as well as other tests, of cellular glass blocks.

Williams (1968) indicates that Styrofoam HI (similar to RM, but used in roadway insulation) can absorb

Table III. Water absorption of Styrofoam RM. Test procedure: ASTM C-240. From Kaplar 1974.

Time	*% by vol*
2 hr	0.124
24 hr	0.336
14 days	0.508
28 days	0.567
90 days	0.763

about 1.8% moisture by volume after 5½ years of service under a roadway.*

This type of evidence indicates that roofing insulation can be expected to absorb significantly more moisture than is shown by short-term ASTM tests.

SAMPLING

Two types of samples were obtained for determining moisture absorption, i.e. sliced and bulk samples. Kaplar (1974) has shown that gross moisture content does not, in fact, indicate exactly where in the specimen the water migrates. Figure A1 in Appendix A shows the results of a 7-day soak of Styrofoam RM and indicates an order of magnitude difference in moisture content depending upon distance from the center of the sample. In a theoretical work, Lee (1972) has also shown that uniform moisture distribution cannot be expected.

Bulk moisture content can be used as an indication of the extent to which the physical properties of an insulation might be affected due to moisture absorption. Williams (1968) showed that for roadway insulation a maximum absorbed water content of under 2% by volume occurred with increasing service. Bulk samples were therefore taken to try to make a mathematical model for predicting expected moisture absorption with time.

Samples were placed in polyethylene bags for transportation to the laboratory. Sample weights were taken using a self-reading analytical balance capable of 0.0001 g accuracy. Samples were dried to a constant weight in a forced-draft oven at a temperature of 25°C. A constant value of 2.5 lb/ft^3 was used in figuring the percent moisture by volume.

RESULTS

Bulk samples

Bulk samples were taken on every roof and every layer of insulation. Each sample was run twice to ensure that abnormal results could be identified easily. The average of these readings was then used as the bulk moisture content. Location of the sample appears to have some bearing on the moisture content. Table IV shows the results of the bulk moisture content determinations. If no location for the sample is shown, then it may be assumed that the sample was taken within 5 ft of a roof drain.

All samples were taken during the fall of the year just prior to continuous freezing weather. The time was selected since it was desirable to test after all expected summer rain had occurred. Aamot and Schaefer (1972) and Aamot (1971) have indicated that protected membrane roofs are self-drying and that moisture content of the insulation is expected to vary with season, hence it was desirable to check for moisture contents after the last of the "rain" season.

Data from Williams (1968) indicate that moisture absorption is a time-dependent function and that after about six years a constant level is approached. To see if the bulk moisture content of roofing insulation could be used to predict moisture levels with time, a statistical analysis was made of these data.

A polynomial regression program† to fit any number of data points to the polynomial equation (of the form: $y = A_0 + A_1x + \ldots A_kx^k$, where $k \leq 4$) was obtained and programmed into an HP9820 programmable calculator. This resulted in an empirical equation:

$$y = 0.124 + 0.0837x - 0.0013x^2 \qquad (1)$$

where y = moisture content in percent by volume
x = length of service in months.

A correlation coefficient between x and y of 0.38 was achieved. This is not generally considered an extremely good dependence factor, but results of this show close correlation when plotted with the Williams (1968) data. Figure A2 shows the plot of eq 1 compared to the data from Williams (1968). As more data become available, refinements in this empirical equation will be possible.

Location of the sample site influences the amount of water present and the duration of time that water

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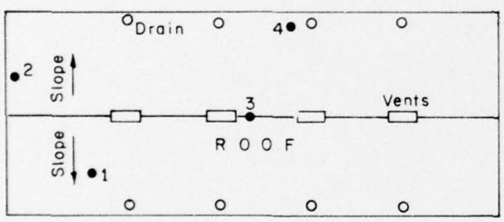
* *It is recognized that roadway insulation experiences only small thermal gradients and lower vapor pressure gradients but data on long term moisture absorption are scarce. Roadway insulation is continuously subjected to soil moisture and does not have the opportunity of drying as do insulations in protected membrane roofs. In some respects roadway insulation undergoes more extreme stresses than roof insulation.*

† *Hewlett Packard 9820A STAT PAC, Program I-B.*

Table IV. Moisture contents of roof insulation.

Building	Moisture content (% by volume)			Thickness each layer (in.)
	Top layer	Bottom layer	Average	
Stevens Hall	0.544	1.551	1.047	2
Building 415	1.397	2.003	1.700	2
Building 1053				
At inst. location	1.016	2.712	1.864	2
At parapet	1.303	1.162	1.232	2
At vent duct	0.443	0.034	0.238	2
At roof drain	2.076	4.360	3.218	2
Gruening Building	0.627	2.084	1.356	1½
Consortium Library				
By roof drain	1.010	Single layer		2
By vent duct	0.415			2
K Building				
By vent duct	0.794	Single layer		2
By roof drain	1.351			2
CRREL, Hanover				
At roof drain	1.554	2.035	1.794	2, 1¼
At roof drain	0.930	2.608	1.769	2, 1¼
Resources Building	0.502	Single layer		3



Location	Moisture %
1	1.86
2	1.23
3	0.24
4	3.22

Figure 1. Roof plan of building 1053, Fort Wainwright, Alaska.

remains in contact with the insulation. Sample sites near roof drains appear to have the most absorbed water. This can be illustrated by examination of the sample sites at Building 1053. Along the centerline of the roof (the highest part), absorbed water contents were 10-15 times lower than by the roof drain. Figure 1 shows the roof plan, along with the sample locations and values for those locations. In most cases where samples were taken at different locations on the roof, the sample taken closest (within 5 ft) to the roof drain had about twice the absorbed water as samples from other locations further removed.

Sliced samples

Kaplar (1974) has shown that insulations do not uniformly absorb moisture. The outer edges tend to absorb much more water than the center. In this study, samples of insulation were sliced into ½-in. wafers and moisture contents of each wafer plotted against distance from the top of the insulation, to provide a series of moisture profiles. These profiles are given in Figures A3-A10. This resulted in two findings:

1. In two-layer systems, the top slice of the top layer and the top slice of the bottom layer of insulation contained the most moisture, with the top slice of the bottom layer generally containing the greatest amount of absorbed water.

2. In single-layer systems, moisture decreases from the top of the insulation to the bottom of the deck.

CONCLUSIONS AND RECOMMENDATIONS

1. Efforts to verify an empirical polynomial equation that will predict expected moisture content with time should be continued. This will require data for a longer period of time; possibly in a year the same sampling program can again be initiated.

2. The exact thermal effects of having absorbed moisture in the insulation should be determined. It is known that the thermal conductivity (Btu-in./hr ft^2 °F) is affected by moisture, but the relationship between increasing moisture content and decreasing thermal conductivity is not known.

3. The use of single layers, rather than double layers, of insulation should be considered. Most manufacturers would probably be willing to make thicker sections.

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APPENDIX A. MOISTURE CONTENTS

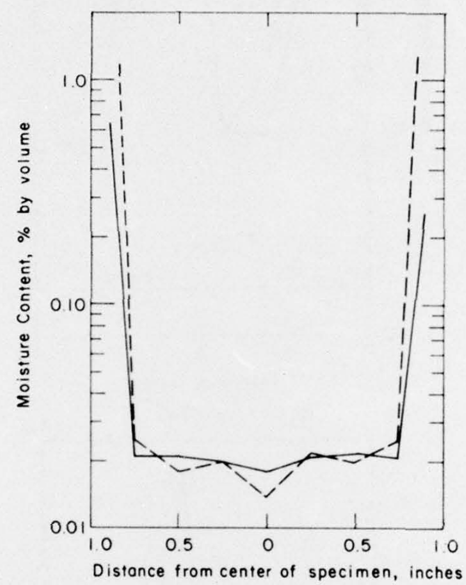


Figure A1. Moisture content of Styrofoam RM after 7 days soaking (Kaplar 1974).

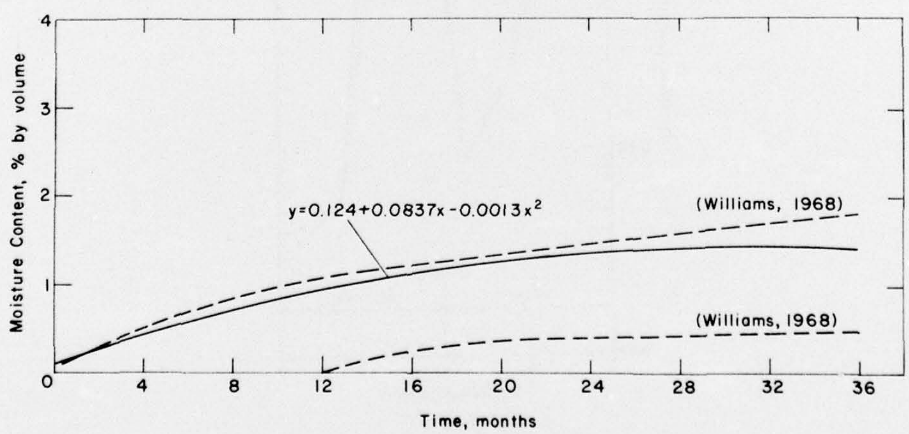
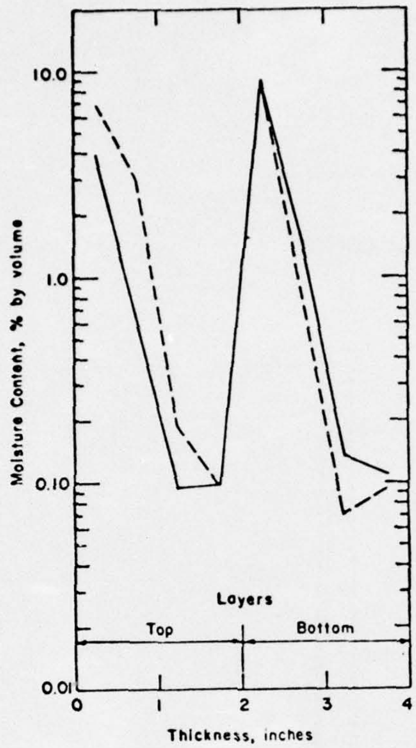
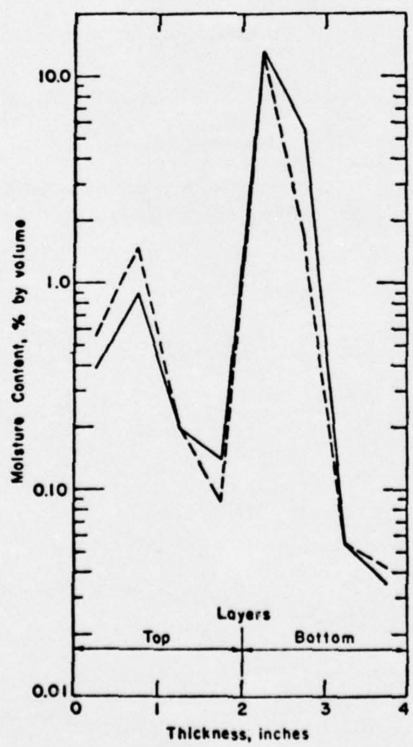


Figure A2. Plot of equation 1.



a. Stevens Hall.



b. Building 415.

Figure A3. Moisture content of roofs at University of Alaska, Fairbanks. (Solid and dashed lines are for separate samples.)

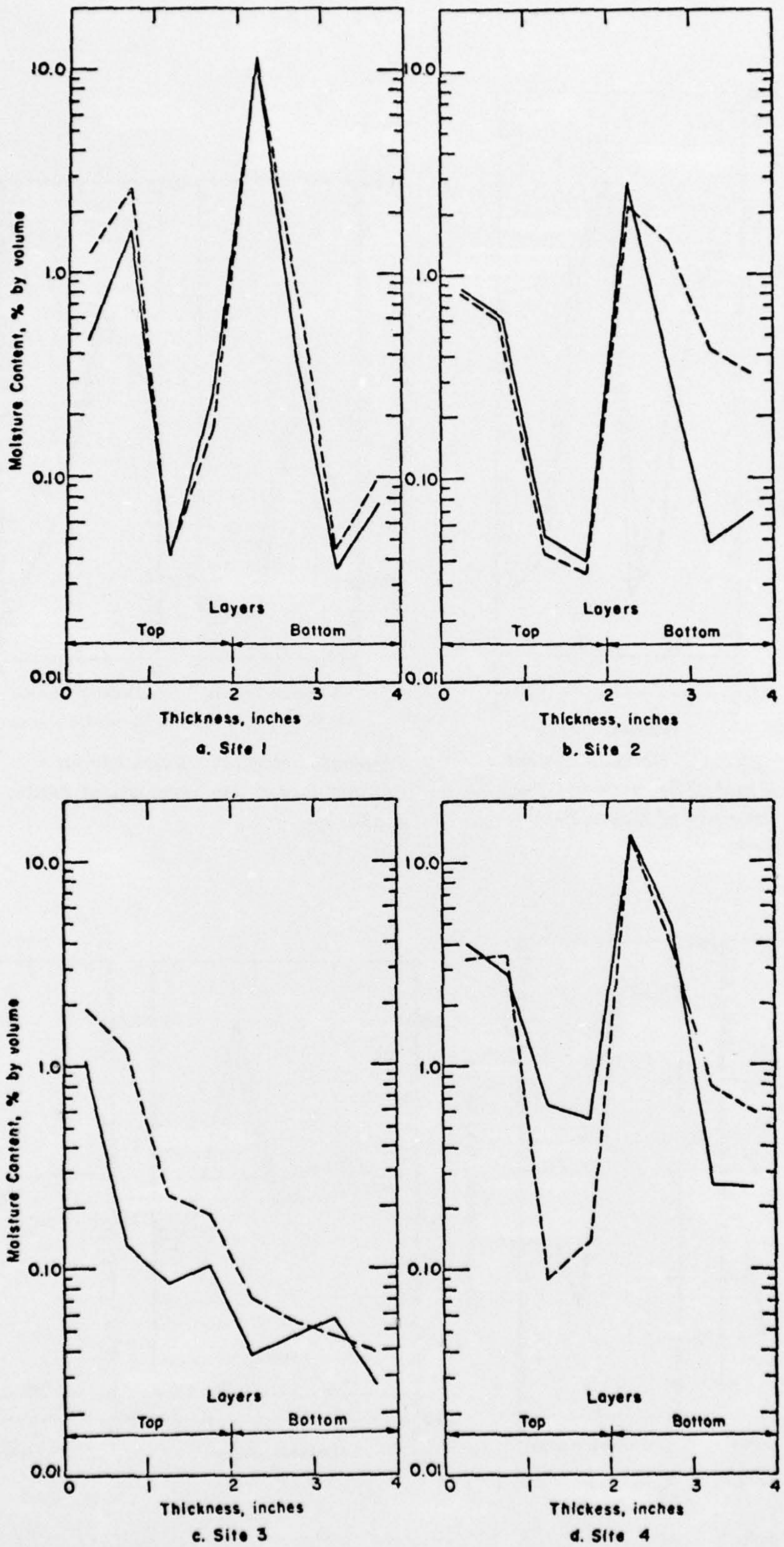


Figure A4. Moisture content of roof of Building 1053, Ft. Wainwright, Alaska.

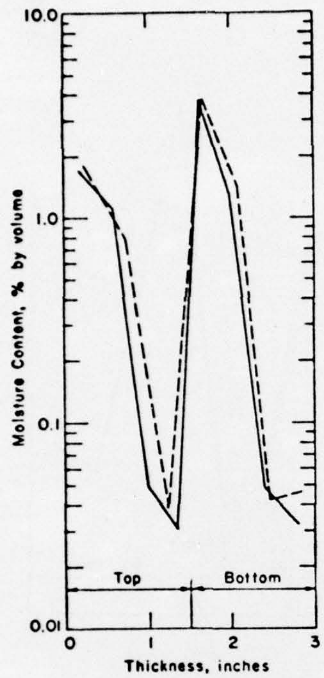


Figure A5. Moisture content of roof of Gruening Building, University of Alaska, Fairbanks.

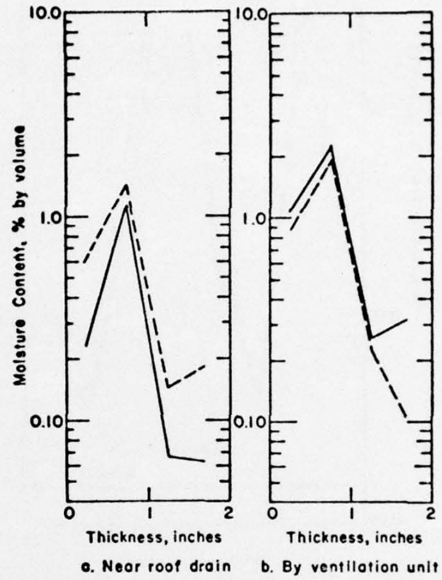


Figure A6. Moisture content of roof of Consortium Library, University of Alaska, Anchorage.

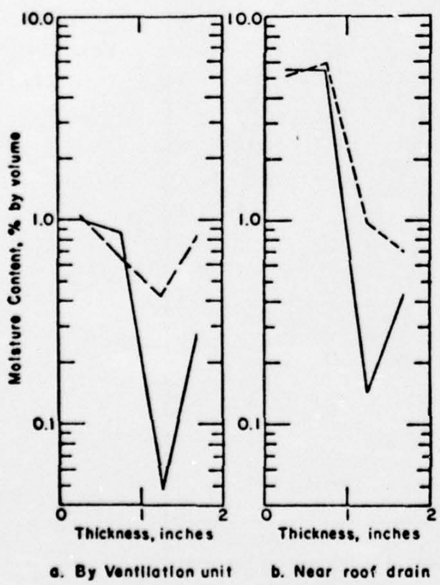


Figure A7. Moisture content of roof of K Building, University of Alaska, Anchorage.

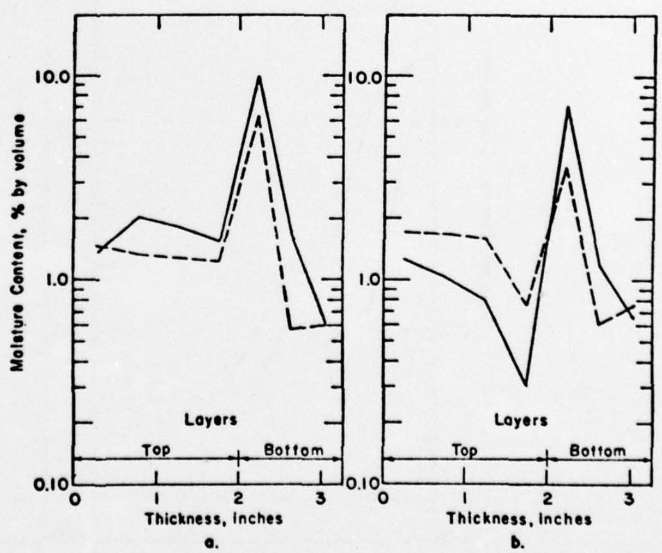


Figure A8. Moisture content of roof at CRREL, Hanover, N.H. (by roof drain).

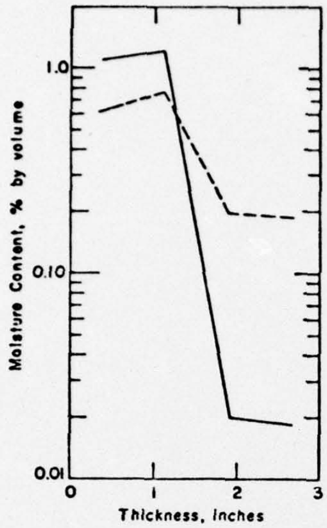


Figure A9. Moisture content of roof of Resources Building, University of Alaska, Fairbanks (by roof drain).

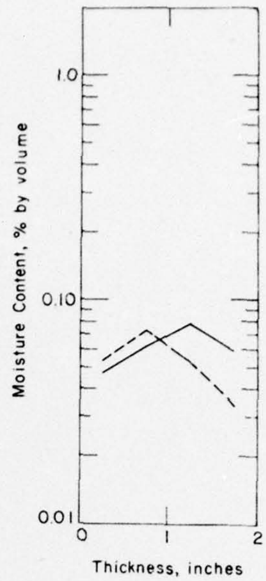
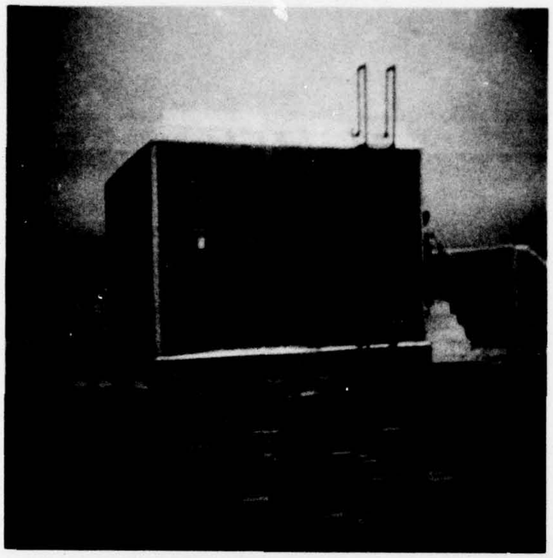
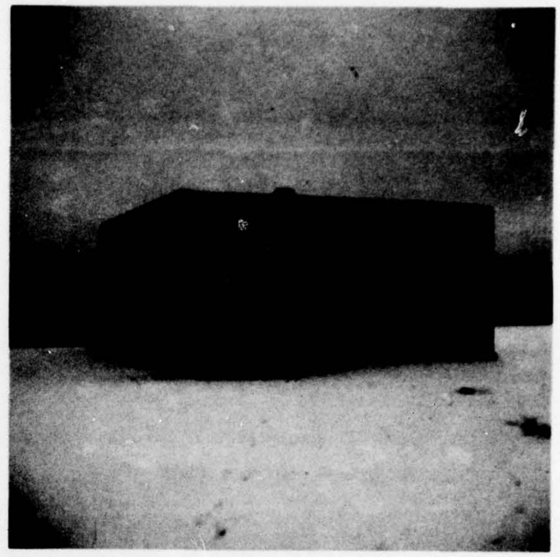


Figure A10. Stored sample used to establish base line.

APPENDIX B. PHOTOGRAPHS

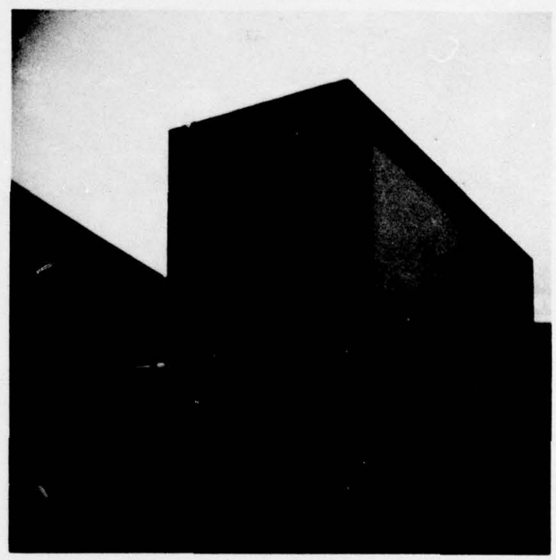


a. Gruening Building, University of Alaska, Fairbanks.



b. Consortium Library, University of Alaska, Anchorage.

c. Resources Building, University of Alaska, Fairbanks.



d. Resources Building, University of Alaska, Fairbanks.

Figure B1. Typical views of roofs sampled.

a. Stevens Hall roof drain.

b. Consortium Library roof drain area.

c. K Building by roof vent.

d. Gruening Building, by roof drain.

Figure B2. Typical sample locations.

a. Building 1053 at instrument site. Some ponded water on membrane. No physical deterioration of insulation.

b. Building 415, University of Alaska, Fairbanks. Condition of insulation is excellent.

c. Single layer system on K Building. Membrane splice is visible. Snow cover 2 in.

Figure B3. Insulation and membrane conditions. (Also see cover photograph.)

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